

JOURNAL OF THE
BOSTON SOCIETY
OF
CIVIL ENGINEERS

SEPTEMBER, 1929

Featuring

**Development of Parks and
Parkways in Westchester
County**

**Rigid Frame Bridge Con-
struction in Westchester
County**



Vol. XVI

No. 7

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Volume XVI

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DEVELOPMENT OF PARKS AND PARKWAYS IN WESTCHESTER COUNTY, NEW YORK

BY L. G. HOLLERAN *

(Presented at a meeting of the Boston Society of Civil Engineers, April 17, 1929)

REGIONAL AND ECONOMIC BACKGROUND

WESTCHESTER COUNTY embraces an approximately funnel-shaped area, including 448 square miles of territory lying between the Hudson River and Long Island Sound on the west and east, respectively, and between the city of New York and Putnam County on the south and north (see map, Fig. 1). It forms the only mainland approach to New York City. It was one of the twelve original counties of the State of New York, erected in 1683 by the Provincial Assembly of what was then the Province of New York. Entirely independent of New York City as a political entity, Westchester County includes forty-five subordinate municipalities, consisting of the four cities of Yonkers, Mount Vernon, New Rochelle and White Plains, eighteen townships and twenty-three villages, having a combined population of about 500,000 people.

New York City's steady growth northward on Manhattan Island and beyond the Harlem River has been reflected in a corresponding growth and expansion of suburban development in Westchester County. This growth has proceeded at an accelerated rate in recent years, particularly in the area south of an imaginary line from Tarrytown on the

* Deputy Chief Engineer, Westchester County Park Commission.



FIG. 1.—MAP OF WESTCHESTER COUNTY PARK SYSTEM

Hudson River easterly to White Plains and Port Chester on the Long Island shore. In the cities of Yonkers, Mount Vernon and New Rochelle, strung across the northerly boundary of New York City from the Hudson River to the Sound, building growth is rapidly closing up the intervening spaces. The smaller communities as far north as Tarrytown and White Plains, although separated by wider spaces, are also growing toward each other at a rapid rate.

From this brief description we may roughly visualize this area with its hitherto practically unplanned suburban development of cities and villages strung along the Hudson River and Long Island Sound, and along the railroad lines through the intervening territory. These various communities are connected by an extensive network of highways, many of them dating from the colonial period, and, until the reconstruction carried on in recent years, a typical rural road system.

Scenic attractiveness, accessibility to New York City and the trend of present growth strongly indicate Westchester County's future destiny as the most attractive residential area of the New York metropolitan district. Industrial development in this area is very limited, and, aside from control through zoning ordinances, the physical characteristics of hill and valley topography make Westchester less attractive for industrial invasion than the flat expanses of Jersey meadows threaded by water and rail transportation facilities.

Broadly stated, the planning problem presented by Westchester County is that of a large satelloid area directly in the only mainland path of growth of New York City, and destined to be devoted to residential purposes as its major utilization, but with local distribution and retail business districts to supply the needs of a greatly increased future population. Among the leading essentials for the planning of this area is the requirement of maintaining and enhancing the natural endowment of attractiveness for residential uses, and the necessity for providing open traffic ways for the large volume of through motor traffic between New York City and upper New York State and New England, which must necessarily pass through Westchester County.

COUNTY PARK SYSTEM

If the map of Westchester be stripped of all other detail, the park system, and particularly the arterial traffic parkways, appears to any one familiar with the terrain as embracing the main elements of a general plan which will very largely mould the future development of the

county. This system should be visualized as having been superposed upon a stratum of existing suburban development which was rapidly closing up all vacant spaces in the southerly part of the county. Naturally the plan could not be wholly idealistic because compromises had to be effected with existing conditions.

The lines of this regional park system were dictated by certain well-defined fundamentals combining not only planning but economic principles involving the following considerations:

Elemental Features. — Water-front parks along the Hudson River and Long Island Sound shores, and interior parks, reservations and forest



FIG. 2. — TIBBETTS BROOK SWIMMING POOL

preserves, providing for a wide range of recreational uses. An inter-connecting system of traffic parkways.

Economic Utilization of Land. — Selection of the cheapest undeveloped lands, such as marshes, stream and pond margins, or rocky uplands undesirable and difficult to develop for residential or business uses, but ideal for park purposes, and as such allocated to their most valuable economic utilization in the general scheme of county development.

Adaptation to Physical Characteristics of Region. — The diversified irregular and somewhat bold topography precluded conventional geo-

metric planning. Such planning could not be rationally or economically adjusted to the physical conditions.

Adjustment to Existing City, Town and Village Developments. — Interwoven with the foregoing was the necessity for effecting the most feasible compromises with existing conditions of the unplanned suburban growth.

Rapidity of Execution. — One of the most important elements was prompt action in acquiring lands in advance of rapidly rising values, leaving the shortest possible gap between planning and the execution of this phase of the program.

Following these basic principles, water-front park areas were laid out at Kingsland Point, Croton Point and Crugers along the Hudson River, and at Glen Island and Rye Beach on the Long Island Sound



FIG. 3. — ARDSLEY ROAD BRIDGE — BRONX RIVER PARKWAY

shore. The main parkway elements of the system traversing the county north and south in the direction of its greatest length follow the valleys of the Saw Mill River, Bronx River and the Hutchinson River, which are separated by north and south ridges paralleling the Hudson River. The interior reservations include Tibbetts Brook Park and Woodlands Park on the westerly side of the county, forming localized expansions of the Saw Mill River Parkway; Willson's Woods, New Rochelle Lakes, Huguenot Woods and Saxon Woods Park along the route of the Hutchinson River Parkway, in the easterly section of the county; and Silver Lake Park near White Plains and bordering a connecting parkway from the Mamaroneck River Valley to the Bronx River Parkway at Kensico Dam. In the open country of northern Westchester at the 1,500-acre Blue

Mountain Reservation of the route of the Briarcliff-Peekskill Parkway; Mohansic Park of 1,100 acres, through which an extension of the Bronx River Parkway will pass; and the Poundridge Reservation, embracing 3,900 acres of forest preserve tied into the parkway system by a main state highway.

The north and south parkways traversing the stream valleys and in the direction of greatest traffic flow serve the multiple purposes of open recreational areas, motor traffic routes of least resistance, the natural drainage routes of trunk sewers, and possible future locations of water supply conduits and other public utilities. The parkway reservations, which include controlling strips of land on both sides of the streams, also forestall the development of nuisance conditions such as developed along the Bronx River Parkway and led to its construction principally as a sanitary improvement project prior to the general county park program. The parkway system is co-ordinated with the older existing county highways. Continuity with New York City's parks stretched across its northern boundary is formed by the Saw Mill River Parkway, Bronx River Parkway and Hutchinson River Parkway, which connect, respectively, with Van Cortlandt Park, Bronx Park and Pelham Bay Park.

PROGRESS

The Bronx River Parkway was the first regional parkways project in Westchester County, and was a joint undertaking between the county of Westchester and city of New York, 12½ miles of the parkway being located within the county and 3 miles within the city. In 1922, three years before the final completion of the Bronx River Parkway, Westchester County launched its greatly expanded park program under authority of a legislative act providing for the establishment of a park system under the administration of a Park Commission, which consisted of six members appointed by the county Board of Supervisors and serving without compensation. After one year devoted to study of the county's needs, the Park Commission made successive reports and recommendations, all of which were adopted by the Board of Supervisors, and the necessary appropriations were unanimously voted.

Five years' active work by the Commission has established a regional park system embracing within the limits of Westchester County 16,671 acres of land, 140 miles of parkway routes, and 9 miles of beaches and shore lines along the Hudson River and Long Island Sound shores. This work has involved the acquisition of about 3,500 separate parcels of land, a large proportion of which was acquired by direct purchase

from owners, thus avoiding the delays incidental to tedious condemnation proceedings.

Coincidentally with the acquisition of land, a construction and development program has carried to completion seven new large scale recreational developments, including bathing beaches, bath houses, concrete swimming pools, a wide range of athletic, recreation and picnicking grounds, three public golf courses, forest preserve areas, and a seaside amusement park embodying a unique and unusual feature under municipal operation. Under this development program 17 miles of fully developed traffic parkways have been completed, giving a total of 29 miles, including the Bronx River Parkway.



FIG. 4. — BRONX RIVER PARKWAY AT WHITE PLAINS AS ACQUIRED BY THE COMMISSION

The Westchester County type of parkway is receiving increasing recognition as the most practicable solution of the arterial highway program from an economic standpoint because these parkways have enhanced real estate values along their routes. In their economic effects a marked contrast is presented by the parkway type of traffic way, creating attractive residential zones and higher property values as against the destruction or depression of values now clearly in progress along modern highways flanked with miles of billboards and hot dog stands instead of marginal strips of grass and trees. The basic practice in laying out these parkways has been to secure strips having a minimum width of 200 feet. In localities where land is cheapest, or there is a

pond or the possibility of developing a water surface feature, localized enlargements of the reservation have been made.

As to the motor driveways, the standard practice is to lay pavements 40 feet wide for four lines of traffic. Grade separations have been effected at all main intersecting thoroughfares which are carried over or under the parkway drive by bridges. The rigid frame type of stone-faced reinforced concrete bridge has been applied to the grade separation problems with very satisfactory results, both as to economy of construction and pleasing architectural adaptations. On the Bronx River Parkway the type of pavement was a concrete base with 2½-inch



FIG. 5. — BRONX RIVER PARKWAY AT WHITE PLAINS AFTER CLEAN-UP

bituminous wearing surface, but the newer projects are standardized on reinforced concrete pavement, with asphaltic emulsion applied to eliminate glare. Grading and bridge openings are being carried through to a width of 60 feet as the necessity for increasing the initial 40-foot pavement width to 60 feet in the not distant future is foreseen.

ECONOMICS

The park program is financed, as to capital investment in lands and permanent improvements, through the standard type of county bonds running from forty-five to fifty years and usually underwritten at an interest rate of 4 per cent. The yearly operation and maintenance charges are carried as an item of the general county budget raised by current tax revenue.

From 1922 to the end of 1928 the total capital appropriations were as follows:

Acquisition of lands	\$32,297,000
Improvement and construction	18,515,900
Total	\$50,812,900

Although not susceptible of exact calculation, it may reasonably be held that the creation of enhanced property valuations has fully offset the capital appropriations, regardless of the public welfare benefits of the park system. The sharp upward trend in assessed valuations immediately after the establishment of the park system is shown by the following figures:

YEAR	Total Assessed Valuation of Taxable Property	Increase
1921	\$676,103,963	—
1922	733,007,069	\$56,903,106
1923	788,029,096	55,022,027
1924	891,331,983	103,302,887
1925	987,068,857	95,736,874
1926	1,143,871,106	156,802,249
1927	1,318,826,453	174,955,347
1928	1,501,531,153	182,704,700

The influence of the park program is apparent in the increased valuations in 1924 and subsequent years. From 1924, when this influence became evident, up to and including 1928, the total increase in assessed valuations was \$713,542,057. At the previous rate of increase the total of the same five-year period would have been about \$300,000,000. An increase of about \$410,000,000, or about eight times the total amount of the appropriation, is therefore reasonably attributable to the park program.

Similarly striking results also have been attained in the rapidity of progress toward the attainment of a self-supporting maintenance basis through revenue derived from rentals, concessions and nominal charges to the public for the use of special features, such as bath houses, swimming pools, golf courses and amusement park features.

The following figures show the rapid trend of earnings toward completely balancing the operation and maintenance budget:

YEAR	Park Operation and Maintenance Budget	Income from Park System	Net Cost of Operation
1922	\$25,000 00	\$275 50	\$24,724 50
1923	54,000 00	126 00	53,874 00
1924	258,308 33	46,191 98	212,116 35
1925	529,529 99	60,944 40	468,585 99
1926	733,103 33	313,102 75	420,000 58
1927	750,125 28	462,518 98	287,606 30
1928	1,202,958 93	1,142,803 36	60,155 57

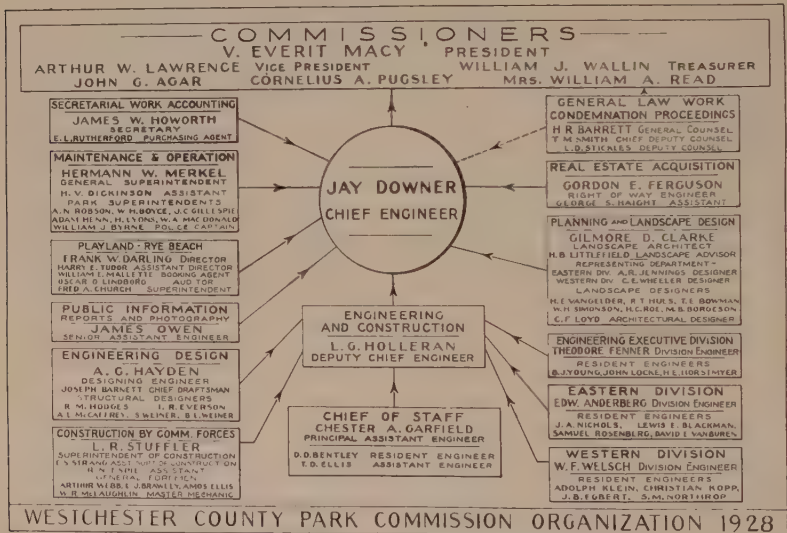


FIG. 6. — ORGANIZATION CHART — WESTCHESTER COUNTY PARK COMMISSION

Although 29 miles of modern highways and an extensive system of recreational projects were in operation in 1928, the net cost to the county was only \$60,155. The parkways yield no direct income, but are of incalculable value in the saving of time, and in convenience and safety for the traveling public.

Although the importance of a regional park system as an item of major importance in planning for the future growth of Westchester was

clearly foreseen, considerable courage was required to launch it as the largest scale improvement program ever undertaken by the county. But officials and leading citizens had full confidence that the ultimate results would amply justify the enterprise. The results which are shown by the foregoing tabulation have been attained in a much shorter period of time than originally was anticipated.

Development work such as above described can be brought about only by means of organization and by means of the closest co-operation of the various professions that ought to be represented in such a development. The engineers probably come first because they have the greatest part of the work to do, but we must also have architects, landscape architects and specialists for various features. The work which I have described has been done by the closest collaboration among all three of these principal branches, and of course accounting and the law must be represented. The organization chart shown in Fig. 6 indicates the organization of the Westchester County Park Commission.

The demonstration afforded by Westchester, that the idealism of a well-conceived planning program may rest on a sound economic basis, is providing stimulus to many other municipalities, both in this country and abroad.

RIGID FRAME BRIDGE CONSTRUCTION IN WESTCHESTER COUNTY, NEW YORK, DEVELOPMENT

BY ARTHUR G. HAYDEN *

(Presented at a meeting of the Boston Society of Civil Engineers, April 17, 1929)

THE principle of the rigid frame bridges being built by the Westchester County Park Commission is illustrated by the toy structures photographed in Figs. 1a and 1b which were constructed of pieces of a hard rubber spline and loaded with an iron weight. In Fig. 1a the horizontal member is simply supported upon the vertical members, and

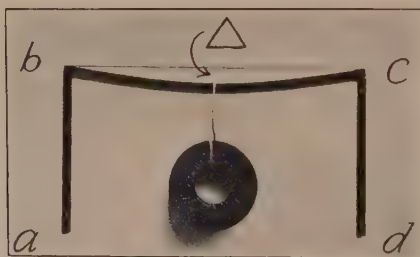


FIG. 1a. — MODEL OF GIRDER ABUTMENT BRIDGE. GIRDER SIMPLY
RESTS ON SUPPORTS

the action of the structure is like that of the simple span beam bridge supported upon its abutments. The vertical members of the toy structure perform no useful work in carrying the load, just as in the beam bridge the abutments serve only to support the active horizontal members and provide the necessary clearance thereunder. In Fig. 1b the same members of Fig. 1a are rigidly connected together, and the structure is continuous from footing "a" to footing "d." The difference of action of the two structures is evident in the photographs. The flexure of the vertical members in the continuous structure is noticeable,

* Designing Engineer, Westchester County Park Commission.

whereas in the simple span structure the vertical members are unaffected by the loads excepting in direct compression. In other words, all three members of the continuous structure are doing useful work in carrying the load. There is, further, a quantitative difference of action in the two structures. The deflection Δ under the load in Fig. 1a is, by actual measurement, about two and one-half times the deflection Δ in Fig. 1b. It is an engineering principle that the work performed in either case is measured by half the product of the load and the deflection under it. We then see that all three members of the continuous structure acting together have to perform only about 0.4 of the work that the horizontal member in the discontinuous structure has to perform alone.

ECONOMY OF RIGID FRAME

The inherent economy of the rigid frame is thus apparent. The abutments of a simple span bridge must have sufficient mass to resist the overturning effect of earth pressure of the approach fill. In the

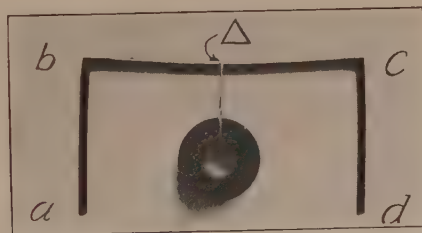


FIG. 1b. — MODEL OF CONTINUOUS RIGID FRAME BRIDGE. GIRDER AND SUPPORTS FORM ONE FRAME

frame bridge the stresses due to earth pressure and those due to vertical loads are counteractive. This is another element of economy.

The rigid frame principle usually permits certain other economies in addition to that in the structure itself, as illustrated in Fig. 2. The vertical clearances over the parkway drive as established by the Commission are as indicated: for a rectangular opening, 13 feet; for arched opening, 11 feet minimum at curbs, and 15 feet minimum at center of drive. Working to these clearances it was found that the rigid frame structure permitted minimum distance from roadway under to roadway over, which is often important. The relative economy of frame and fixed arch with its massive abutments (necessary to realize the condition of fixity at the ends of the arch rib as assumed in design) is apparent. Moreover, the fixed arch requires a certain minimum rise of arch ring

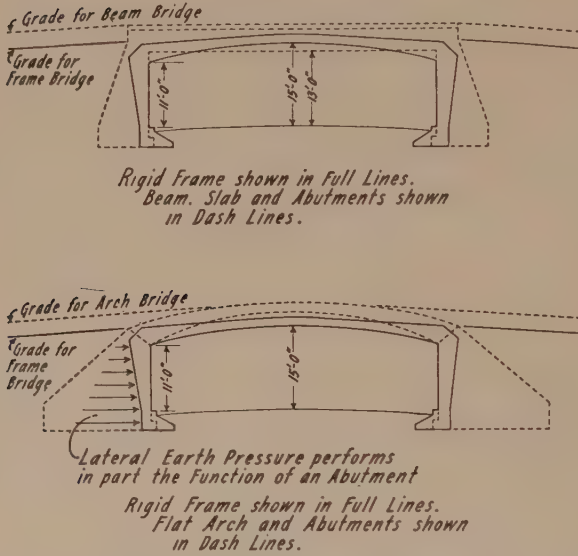


FIG. 2. — COMPARISON OF RIGID FRAME DESIGN WITH USUAL FORMS OF BRIDGE CONSTRUCTION

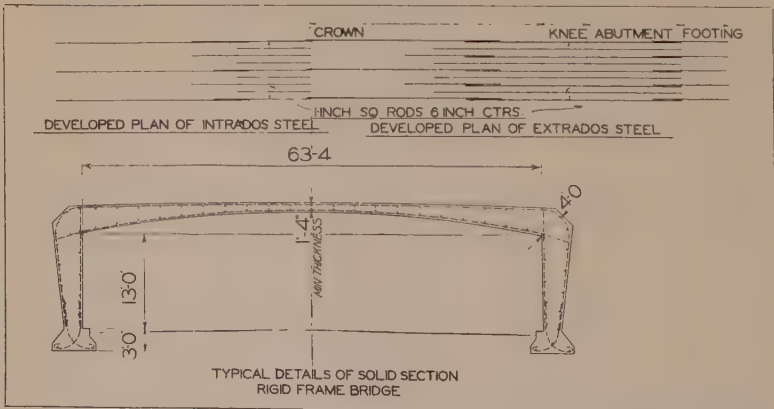


FIG. 3. — TYPICAL DETAILS OF A CONCRETE RIGID FRAME BRIDGE.

proper to meet temperature stresses, whereas the rise from springing to crown of the top member of the rigid frame is unimportant. The result is a considerable saving in cost of approaches for the frame structure as compared with either the beam or arch bridge. It will be noticed in Figs. 2 and 3 that the members of frame bridges, as actually built, are not of constant thickness as in the toy structure of Fig. 1*b*. The material is placed where it is most effective in performing useful work in carrying the imposed loads. As a matter of fact, the constant section frame would be impracticable for bridges of the size of the Westchester bridges.

Fig. 3 shows typical details of a 63-foot clear span concrete frame bridge. The reinforcing steel pattern is simple, and very few sizes and lengths of main rods are used in the entire structure. Fig. 4 shows a completed bridge of rigid frame type faced with stone, which is an architectural feature of the Westchester County Parkway bridges.

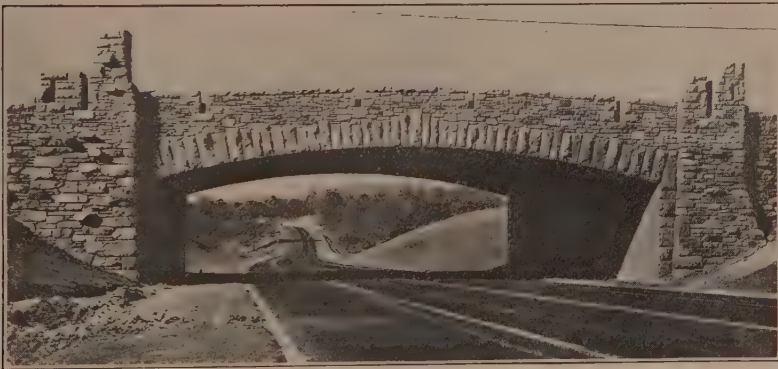


FIG. 4. — RIGID FRAME BRIDGE FACED WITH STONE

VARIETIES OF DESIGN

Figs. 5 to 11 show varieties of rigid frame bridges used for grade-crossing eliminations on the parkways. Fig. 5 shows a structure for double driveway. Fig. 6 is a ribbed type bridge consisting of a number of longitudinal rigid frames carrying a floor deck and having end cut-off walls to retain the approach fill. This construction was used for a few skewed bridges, built before design methods for solid barrel skewed arches or frames had been developed. Certain effects of skew exist in the ribbed structure, and were accounted for in design, but other effects then little understood were mitigated. Fig. 7 shows a completed bridge of ribbed construction, but not the same structure as shown in

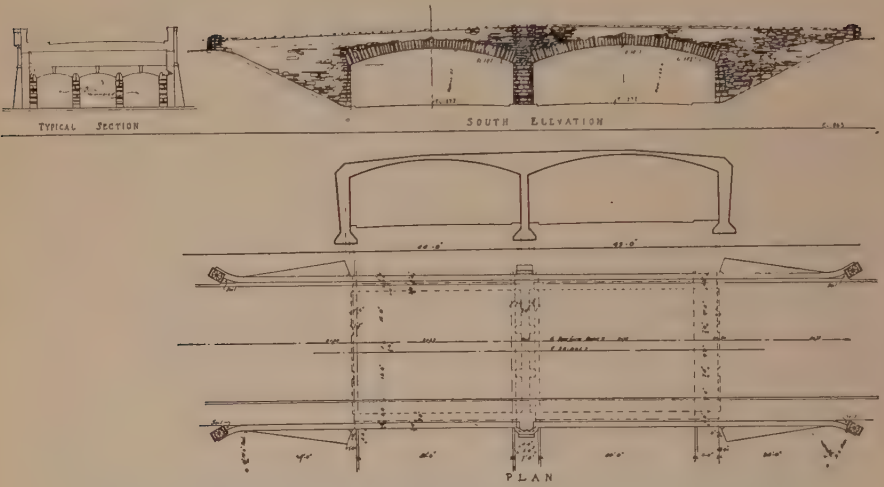


FIG. 5. — DOUBLE-SPAN BRIDGE DESIGNED FOR PARALLEL DRIVES

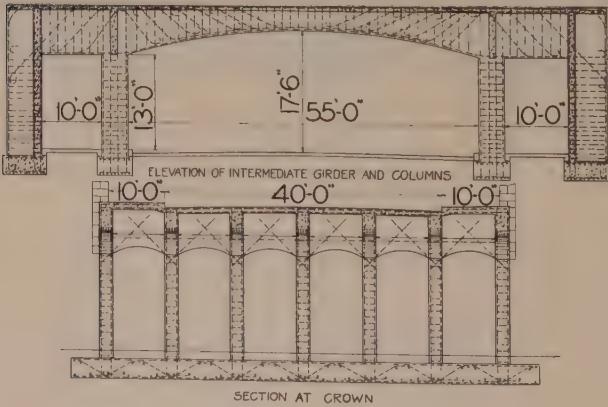


FIG. 6. — RIBBED TYPE OF BRIDGE



FIG. 7. — A COMPLETED BRIDGE OF RIBBED CONSTRUCTION

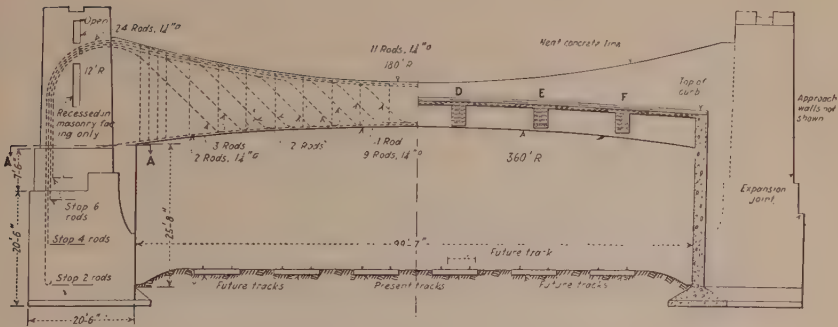


FIG. 8. — VALHALLA BRIDGE

Fig. 6. Fig. 8 shows a through girder bridge consisting of two reinforced concrete frame girders carrying transverse floor-beams upon which is placed the floor slab. This is the Valhalla bridge shown completed in Fig. 9. Figs. 10 and 11 show a rigid frame bridge consisting of several longitudinal steel rigid frame girders carrying a reinforced concrete floor deck. In the completed bridge the vertical legs of the girders are behind the reinforced concrete cut-off walls which retain the approach fill, and are encased in concrete and buried in the approach fill.

COMPARATIVE ESTIMATE OF COST

[Various types of construction: single-span bridge, clear span, 76 feet; clear width, 40 feet. Underclearance, 14 feet for steel girder bridge. Minimum underclearance for frame and arch bridges, 13 feet at curbs, 15 feet at center line of road under.]

	Main Structure	Approaches	Total
Concrete frame bridge	\$27,000	\$42,000	\$69,000
Steel frame bridge	27,000	42,000	69,000
Simple span steel girder	31,000	52,000	83,000
Concrete fixed arch	35,000	40,000	75,000

A comparison of cost of various types of construction for a 76-foot span bridge carrying a 40-foot roadway is given in the table. The girder bridge estimated here is of the usual construction, — two longitudinal girders carrying transverse floor-beams, and longitudinal stringers with reinforced concrete floor deck. The gravity abutments are figured in with the superstructure as "structure proper." Another type of construction, consisting of a number of longitudinal steel I-beams carrying a reinforced concrete floor deck and supported upon gravity abutments, has been found more economical than any type estimated in the table for the short span river bridges built by the Commission; but the exact economic limits of the steel or concrete frame types have not been determined. This is one of the problems that the colleges and universities, which are assisting the Commission in research work, are engaged in. As the results of such research come in, the story of the rigid frame bridge is being written.



FIG. 9. — COMPLETED VALHALLA BRIDGE — BRONX RIVER PARKWAY
(Structural details shown in Fig. 8)



FIG. 10. — MOUNT PLEASANT RIGID STEEL FRAME BRIDGE
UNDER CONSTRUCTION

Structure of 100-foot span carries Westchester County,
N. Y., highway over New York Central Railroad tracks

SKEWED FRAME BRIDGES

One of the outstanding achievements of recent times in the field of structural mechanics is the solution of the skew arch problem by Prof. J. Charles Rathbun, formerly of the University of Washington, now of South Dakota State School of Mines. There have been many serious failures of skewed barrel arch bridges which were designed according to accepted methods before the action of such structures was understood. Following the appearance of Rathbun's paper on the



FIG. 11. — THE MOUNT PLEASANT BRIDGE COMPLETED

"Analysis of Stresses in the Ring of a Skew Arch," in Transactions, A. S. C. E., 1924, and the verification of his mathematics by the classical deformeter tests of Professor Beggs of Princeton University, the Westchester County Park Commission engaged Professor Rathbun to solve the like problem of the skewed frame bridge. His solution was applied to the redesign of Fenimore Road bridge, which is a reinforced concrete frame structure on 50° skew. The span of this bridge is 42-foot square distance, 70-foot skew distance, and the clear width, 44 feet. A design had been made for a ribbed structure of the type previously described,

so that a direct comparison could be made between the ribbed and solid section types. A saving of about \$6,000 in structure and approaches was effected by the solid barrel type of design, and a more presentable structure was secured. Several skewed frame bridges have since been built and design methods improved. Fig. 12, for a frame bridge of about 30° skew, shows the principal forces introduced by the skew which must be accounted for in design. The various thrusts, shears, moments and torsional forces combine in such manner that the system or reinforcement is decidedly affected thereby, as will be noticed by comparing Figs. 3 and 13. There is no main transverse reinforcement in the square bridge, although a nominal amount is used to bind the structure together, as well as to support the main steel and keep it in

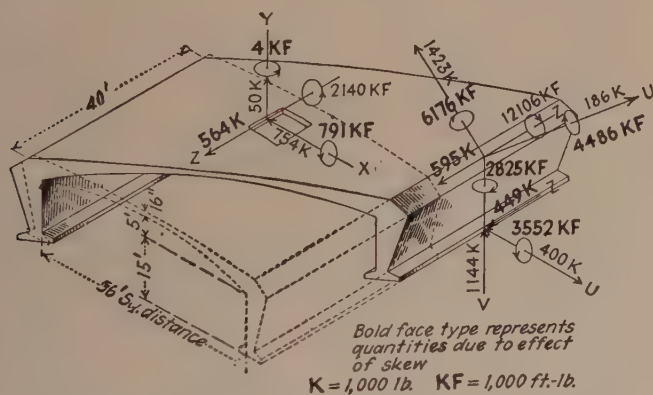


FIG. 12. — PRINCIPAL FORCES IN SKEW BRIDGE

place during construction. In the skew bridge (Fig. 13) a very considerable amount of transverse reinforcement is required to carry calculated stress. Neglect to provide for such stresses introduced by the skew has been the primary cause of many skew arch failures. Many incorrectly designed arches do stand up, but it is obvious that their factor of safety must be greatly reduced, though it may not be to the point of actual failure.

MODELS TESTED AT COLUMBIA UNIVERSITY

The safety of our rigid frame bridge design was questioned by some engineers before we had had experience in its construction, the contention being that dangerous conditions of stress would be developed under

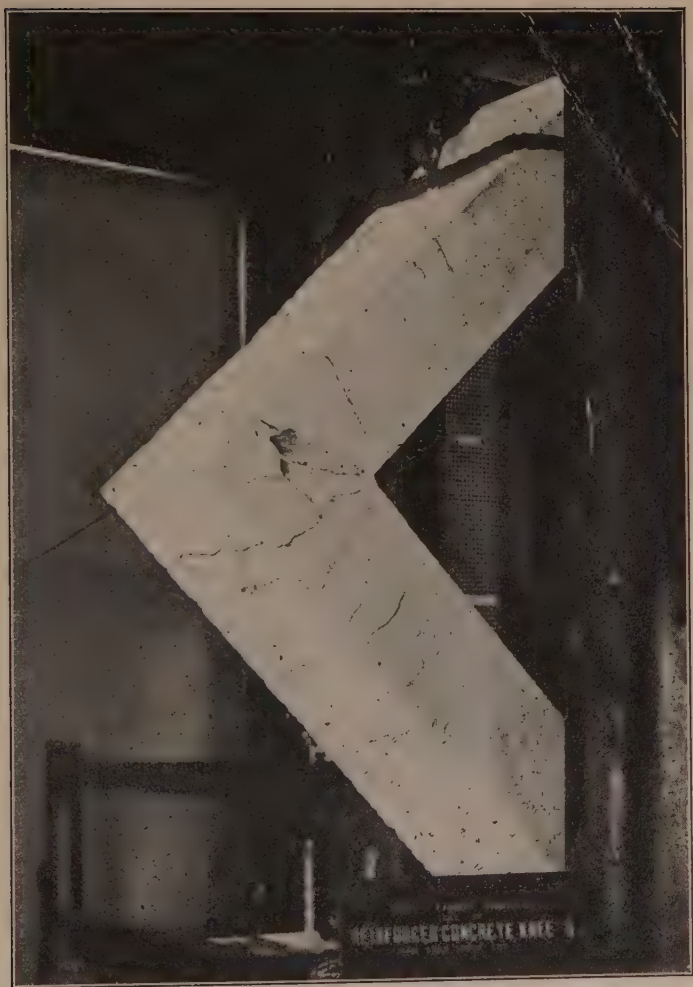


FIG. 14. — TEST OF KNEE MODEL. MAXIMUM LOAD
19,300 POUNDS

bending moments that might be expected of straight beams of the quality concrete shown by the test cylinders accompanying each model and tested for elastic properties and ultimate compressive stress. The prediction that peculiar conditions of stress under load would be found to exist at the knee or bend was, however, verified. The position of the neutral axis in the square corner specimens may be traced in Fig. 14 by following the termini of the hair cracks which were outlined in black crayon on the whitewashed surface of the specimens. Notice that the neutral axis comes in very close to the corner, and that in



FIG. 15. — FIELD MODEL TEST

consequence there must be very high compressive stresses concentrated at this point, and correspondingly low tensile stresses on the opposite or tension side. In spite of the high compressive stresses observed there were no compressive failures, and the satisfactory results of the Columbia tests demonstrated the safety of the detail. The explanation of this will have to be left to the experts in structural mechanics. It may be observed, however, that the high compressive stress in the inside corner is in the nature of a confined stress, compression coming in from all directions, along each leg and inward from the outside projecting corner. The effect of the fillet used in three of the specimens was to

throw the neutral axis out farther and reduce the high compressive stress existing in the square-cornered specimens. The ultimate load carried was greater, but this was due apparently only to the reduction in the length of lever arm to the critical moment section. The ultimate bending moment was apparently no greater than in the square-cornered specimens.

The Columbia tests caused some controversy, but Professor Frost's recent research upon small celluloid models of knees by photo-analysis confirms in general the results of the Columbia tests. While the conditions of stress revealed by photo-analysis may be somewhat modified in a non-homogeneous reinforced concrete structure, it is safe to conclude that the main characteristics will be the same. Further discussion will be left to Professor Frost.

ADDITIONAL TESTS

In addition to the Columbia University tests, two field tests were made upon reinforced concrete models of a full span rigid frame shown in the photographs (Fig. 15). These models had a span of 10 feet clear, width of 3 feet, height of 4 feet, crown thickness $3\frac{1}{2}$ inches, knee thickness $10\frac{1}{2}$ inches. They were proportioned for uniform load, but tested for a load concentrated at mid-span and without the support of earth pressure at the ends, which would tend to relieve the critical stresses. The construction forces who were engaged in building the Swain Street rigid frame bridge (shown in the background), which was parent to these models, did not have the same respect for the toys of the theorists, and construction defects in the models greatly impaired their capacity. Despite this, each supported a load of 13 tons with calculated unit stresses of 79,000 pounds per square inch in the reinforcing steel, and 4,900 pounds per square inch in the concrete, the stresses being calculated for the actual effective depth to the misplaced steel which was afterwards determined by breaking up the specimens. These tests demonstrated the great load-carrying capacity of the rigid frame construction, and also illustrated another characteristic of their behavior. Since the models were proportioned for uniform load, and tested for a concentrated center load, the crown section developed its full capacity before other parts of the structure. Failure did not occur at this stage, however, as would have been the case in a simple span structure, but other parts continued to perform, and loading was increased until failure as a whole occurred. The crown had been stirruted so that overstress did not cause actual collapse but permitted the structure to function as though partly hinged at the crown.

RESEARCH IN COLLEGES

The development of our rigid frame bridge construction has been greatly facilitated by research in colleges and universities, chiefly by students for advanced degrees. Massachusetts Institute of Technology, Columbia University, North Dakota State School of Mines, Union College and Rensselaer Polytechnic Institute have contributed to the solution of problems and are still contributing. Comparative effects of partial or full restraint at the footings have been studied, effect of change of span length due to soil yielding or other causes, effect of unequal settlement of footings, effect of passive earth pressure developed by flexure in the structure, and so on. One of the interesting studies is the effect of relative proportioning. If for any reason it is inconvenient to increase the depth of section at a particular point in order to meet stress conditions, the situation can be solved by increasing the section at other points, thus changing the balance of the moment curve. This is due to the fact that in such indeterminate structures the stresses at any particular point are a function of the elastic properties of all parts of the structure. As the results of these studies come in, the story of rigid frame bridge construction is being written, and its economic limits in comparison with other types is being discovered. The width of bridge, methods of erection (with or without falsework), established underclearances, effect of floor depth upon approaches, and many other factors enter into the question of economic limits, and their relative effects cannot be determined without considerable study and a critical comparison of the results of experience.

The adoption of this type by others is a very satisfactory demonstration of its practical value. New York State, Connecticut, Rhode Island, Oregon, the Long Island State Park Commission and the New York Central Railroad have used it for some of their bridges, and other state highway departments and railroad companies, as well as visitors from foreign countries, are studying the development with the same end in view. In a very few instances adverse reports have been received as to the economy of the type compared with ordinary construction, but in such cases the problem has been confused with the elaboration of architectural treatment or some other factor pertaining to a particular case.

In this departure from traditional methods of construction the writer has received the support and encouragement of the deputy chief engineer, Mr. Leslie G. Holleran, the chief engineer, Jay Downer, and the Commissioners.

Discussion

PROF. CHARLES M. SPOFFORD:* The papers which have been presented this evening have been full of interesting and valuable material, and the views shown by Mr. Holleran, illustrating the conversion of unsightly dumps and swamps into beautiful parkways, were highly instructive. The fact that this park system, in spite of the large expenditures for playgrounds, beaches, golf links and other similar features, is practically self-supporting is noteworthy.

With respect to rigid framed bridges, which were discussed by Mr. Hayden, the speaker considers that the development of this type of bridge forms a valuable addition to the art of bridge design, and wishes to congratulate Mr. Hayden and his associates for the initiative, courage and thoroughness they have shown in carrying on this work. The increasing use of continuous structures in this country during the last twenty-five years is one of the interesting developments of structural engineering, and while largely confined to reinforced concrete construction where continuity cannot well be avoided, a considerable number of important continuous bridges have been built in recent years, these bridges having practically all the advantages of cantilever bridges with respect to erection stresses, but being more economical of material and more rigid.

Apropos of the development of continuous structures, some one told me the other day of a discussion between two engineers as to the relative advantages and disadvantages of continuous structures. One of them said to the other, "I don't believe in designing any structure unless I can figure the stresses in it." The answer was, "Neither do I, but why don't you learn how to figure stresses?"

PROF. LEWIS J. JOHNSON:† I should like to hear more about what becomes of that compression. I don't think that the speaker has had time to explain it fully. I am gratified that it appears not to be so serious as one might suppose. I am also pleased to infer that the construction of this important and often advantageous type of bridge is destined to become so standardized that in many instances it can be used with safety and economy by engineers not specialists in the analysis of indeterminate structures.

MR. HAYDEN: The compression does not disappear, and although it piles up to great magnitude at the inside corner, it appears to be

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safe — probably as a confined compressive stress under the particular existing conditions. I can only offer analogies as to why in this case a high compressive stress is safe, and leave it to the experts in internal stress mechanics to explain the reason. In compressive tests we obtain higher values for flat plates than for concrete cubes. In the first case we approach a true compression, whereas in the second case there is latitude for shearing failure along inclined planes accompanying the compression — in reality a combined stress failure. Likewise, in calculating the shearing capacity of a concrete beam, where we have considerable tension coexistent with shear, we allow 40 pounds per square inch, whereas in calculating punching shear in a flat plate we may use a much higher value. In the first case the shear is used as a measure of diagonal tension (shear in presence of tension), whereas in the second case the effect of tension is subordinate, and true shearing resistance is the controlling factor. Another analogy is afforded by water which we ordinarily conceive as lacking in tensile strength because it flows so readily. In fact, water has some tensile strength, but no resistance to shear on any plane. If confined in a capillary tube, where the effect of shearing failure on any inclined plane is subordinated, a tensile strength of several pounds per square inch is revealed. The capacity of a member is therefore determined not by the calculated compression or tension or shear by itself, but by the condition of combined stress produced by the applied loads. In the knee models tested, stress comes into the corner from all directions, producing a confined compression for which a high unit value is safe.

PROFESSOR JOHNSON: There is one point in which I am not quite in agreement with the speaker. I think it unnecessary and perhaps misleading to attribute any importance in this instance to shear and compression being combined. There is nothing unusual about shear and compression occurring together; or about failure from a compressive load being due to the shear, which, as well as compression, is caused by that load. Take an ordinary concrete prism tested in what we commonly and conveniently call compression; it commonly fails by shear. It is not important that compression exists in the prism as well as shear. What decides the issue in such cases is shear, and the concrete's inability to withstand that shear. On the variously inclined planes through a given point, the unit-stresses vary not only in character, but vary widely in amount; and failure simply takes place as usual through the weakness of the material in the plane on which unit-stress first oversteps the ability of the material to resist that particular kind of stress. And that dominating kind of stress, even in a so-called compression mem-

ber, is often shear. In that case the controlling weakness is shearing weakness. Similarly, in material subject to shear the controlling weakness is sometimes tension acting on a plane other than that subject to the carefully computed and much talked of shear.

An interesting illustration of this last point occurs in connection with the 40 pounds per square inch shear which we take as the upper limit of "shear" at the ends of reinforced concrete beams. That limit is so taken only because in such a case that very moderate shearing intensity indicates tensile intensity of an equal and perhaps controlling amount on another plane. When, however, we have 650 pounds per square inch compression on the right section at the top at mid-span of a simple beam, and although there is at the same time 325 pounds per square inch of shear on a plane at 45° with the vertical, we properly pay no heed, despite the fact that the shear is then more than eight times the 40 pounds taken as the upper allowable limit on the right section at the end of a beam without web reinforcement. The reason is simply that in the one case the 40-pound shear indicates a 40-pound per square inch tension at that point — on another plane, of course; whereas in the other case the 325-pound shearing unit stress does not indicate presence of any tension at all at that level, or of any important tension anywhere on that side of the neutral axis.

We do not need to speak of the mixture of stresses, but simply to examine the unit stresses on planes variously inclined. In that quarter, I think, lies the explanation of the high compressive strengths appearing to exist at these knees. Knees do not fail under computed compressive unit stresses which under some conditions prove ruinous, because in these cases the compression comes from two directions at right angles to each other, and there is not only no tension on any plane in the region of high compression nor much if any shear in any plane parallel to the springing line. Even in planes otherwise directed the higher unit shears can prevail over only very restricted areas, and only at or very near the exposed or spandrel faces, at that. Even here, where it would easily be seen if it occurred, no spalling is reported. The body of the concrete, free from dangerous tension or shear, confined somewhat like a fluid under hydrostatic pressure, must, like even the fluid, be able to offer very high compressive resistance — far higher than can be offered by axially loaded concrete prisms or the compression top flanges of beams. What the upper limit of that resistance may be is hard to say, but experience with these knees seems to be showing that it is at least adequate for these cases in spite of *a priori* reasons for expecting the contrary.

MR. HAYDEN: That is right. In the case of the knee models the compression is held there and can't get away. The calculation of internal stress in a structure is a relatively complicated problem. My analogies of combined stress show that rules of thumb take cognizance of the relative effects of calculated tension or compression or shear as a crude measure of the true internal stresses.

QUESTION: I should like to ask about the deflection in that 100-foot span. You said it was only 2 feet deep at the center. Wouldn't you get quite a large deflection?

MR. HAYDEN: We have not had the opportunity to make any refined measurements on our bridges. In a few cases we have made crude measurements of the deflection of concrete frame bridges under load and found them to be very rigid. On one structure, 64-foot span, designed for very light loading (80 pounds per square foot), we measured the deflection under a 32-ton excavator carried on a 10-ton carrier, and could not detect over one-sixteenth inch deflection. We also measured crudely the deflection of the first half (20-foot width) of the Swain Street bridge under four 10-ton tractors before the arch ring stone facing had been constructed. This was a 42-foot span rigid frame bridge, and we recorded less than one thirty-second inch deflection. The question of calculated deflection in rigid frame bridges is one that is being studied now under our direction by a college student, as a thesis for his degree.

QUESTION: Does the temperature cause enough deflection in the vertical members to cause trouble with the pavements?

MR. HAYDEN: No, the temperature deformations are small. For our first rigid frame bridge designed we had about 200 pages of calculations. We figured it out from various viewpoints, — settlement stresses, shrinkage stresses, temperature stresses, etc., — and found that the temperature stresses and deformations were small in amount. You can see the reason for that by analogy with the arch. In a very flat fixed arch (having a small rise-ratio) the temperature stresses are large. In a fixed arch of full semicircular section the temperature stresses are smaller. In a two-hinged arch of semicircular section the temperature stresses are negligible. The rigid frame structure is analogous to the two-hinged arch with large rise-ratio. The temperature stresses are small and the temperature rise and fall of the crown is correspondingly small.

QUESTION: What is the effect of small movements of the foundations?

MR. HAYDEN: We figured some structures for one-half inch of movement out or in of either abutment, and for one-half inch of uneven

settlement of one abutment below the other, and for such deformations the stresses were small. Another student studying for a master's degree is preparing a complete mathematical investigation of these points. Such disturbances are usually negligible in effect.

PROFESSOR JOHNSON: I wonder if I am right in assuming that you make the bottoms of each of those footings practically flat?

MR. HAYDEN: We make them flat when the horizontal component combined with the vertical gives small inclination to the reaction; that is, less than the safe angle on soil. In one bridge having 80-foot span and low rise we have considerable thrust at the bottom and the reaction has a steeper angle. In this structure (the Bronx River Road bridge) we had one abutment on rock, so the footing was reinforced like a building column and set into the rock. The other footing on soil foundation was inclined at the bottom approximately perpendicular to the reaction, so that it would have no tendency to slide. Ordinarily that is not necessary; they are usually flat.

PROFESSOR SPOFFORD: I am under the impression that Mr. Hayden said that the bridges he has been telling us about are computed as if hinged at the bases of the columns. I don't know what the soil conditions under the footings of the various bridges of this type, which have been constructed by the Westchester County Park Commission, may have been, but I judge from the views that at least most of them were in good material which would not readily adjust itself to correspond to the assumed conditions required by a hinge. I should like to inquire if any cracks have appeared in the footings of any of the columns.

MR. HAYDEN: The structures are not designed as hinged just above the concrete footings, but are designed continuous right down to the ground so as to prevent cracks above the spread portion designated as the footing. The assumed hinge for design purposes is at the bottom of the footing. Allowance for restraint at the footing is made by assuming the reaction to move within extreme limits, that is, by assuming a traveling hinge. Unless the footing is actually anchored to the ground so as to develop tension on one side or the other of the center of base, the reaction cannot, of course, travel outside the base, nor, in fact, very near to the edge, without producing impossible conditions of soil pressure. Ordinarily we do not have to take account of restraint at the footing.

PROFESSOR SPOFFORD: If you build such structures on piles you would have to take account of the fact that no hinges actually exist in the bottom of the column, and that, in consequence, even under vertical

loads, the loads on the pile footings would be eccentric and thus increase the required number of piles, would you not?

MR. HAYDEN: Then we do take account of it. We found that the cost of allowing for complete fixity was about \$100 for extra steel reinforcement. In case of pile foundations we design for hinged conditions at the base of footing, and for complete fixity, whichever governs the stresses at any given section. In this way any possible degree of restraint is covered.

QUESTION: I noticed in one of the sketches the vertical reinforcement of the walls crossed below the top of the footing. Wouldn't that give a condition approaching a hinge? The reinforcing would be in the middle where they crossed, and there would be a fair chance for the concrete to crack at that point, possibly 2 feet above the footing.

MR. HAYDEN: No. At the point of crossing (below the top of the footing and a little above the bottom) there would be little if any calculated tension in the concrete. The footing itself is designed as any cantilevered column footing is, and bringing the reinforcing rods down from the vertical walls and bending them around into the footing is only a convenient way of reinforcing the cantilevered portion of the footing. No attempt is made to provide a flexural hinge, and any tendency to cracking in the concrete is provided against.

QUESTION: Will Mr. Hayden please explain what type of bars he used?

MR. HAYDEN: We used deformed bars, because they are carried in stock and are easy to get. The stress comes into the reinforcement throughout the rigid frame very gradually, therefore mechanical bond is not necessary. You could, therefore, use plain bars just as readily as deformed bars, but the latter are on the market and easy to buy.

PROFESSOR SPOFFORD: While in Rome, in 1911, I was interested in the bridge which had been recently constructed across the Tiber, — the Risorgimento bridge. In Rome one finds sharp contrasts between constructions built by the ancient Romans and those of modern times. This new bridge, as compared with the old Roman structures, impressed me very strongly by its apparent boldness of design, particularly the thinness of the crown of the arch. As a matter of fact, I hesitated to cross it until I saw trolley cars passing without causing any apparent ill effects. The arch was so thin at the crown that it was quite evident that the bridge could not have been designed as an ordinary arched structure, and I have come to the conclusion that it may have been planned as a rigid framed structure, similar to those discussed by Mr. Hayden tonight. I have no definite information along this line, and

possibly this is not the case, but I am convinced that, if figured by the ordinary arch theory, the bridge would be found to be greatly overstressed. I would like to ask if Mr. Hayden is familiar with this bridge and knows whether it was designed as a rigid framed structure or not.

MR. HAYDEN: No. We tried to find a parallel for these rigid frame bridges, and, if any had been built, how they had been designed, so that we could take advantage of what had been done before. But we were not able to find a parallel case. There was one German engineer who came over from abroad who seemed to know about rigid frame construction, and had had something to do with the design of rigid frame train sheds built in Germany. He told me that the examples of European rigid frame structures he knew about had been designed on the basis of constant moment of inertia. I don't know that that is true, but that is what he told me. Formulas for constant section frames have been derived by integral calculus, and where there was variation in construction it was kept within limits so that the error introduced by the fact that the moment of inertia was not exactly constant would be small. He said that our methods were at that time original and greatly increased the application of rigid frame construction.

QUESTION: I should like to ask the reason for the variation in the clearance diagram from 15 to 11?

MR. HAYDEN: The clearance diagram was given to the designers by the Commission: 11 feet at the curb and 15 feet in the middle. Mr. Holleran will know more about the reason for its adoption than I. I suppose it is more efficient than a rectangular opening of, say, 13 or 14 feet would be, because vehicles of ordinary height can pass under for the full width of roadway, and a vehicle of unusual height can pass under near the middle of the drive, where the clearance is 15 feet.

MR. LESLIE G. HOLLERAN: I think I explained that when I was talking about the grade crossings. The state requirements in New York are 14 feet clearance. What I showed for the commercial vehicles was 13 feet at the curb and 16 feet at the crown. The reason why there is a variation is in order to obtain the arch appearance we want on these bridges. If we didn't have a variation between the clearance at the curbs and at the crown we would, of course, have a flat girder, which we were trying to avoid. On the passenger vehicle diagram we had 11 feet at the curbs and 15 feet over the middle of the road, which gives a more graceful appearance.

QUESTION: I should think the vehicles would naturally keep to the side of the road.

MR. HOLLERAN: For commercial vehicles we allow 13 feet at

the curb. The Highway Department is designing its bridges for 14 feet. We were attempting to reduce the rise and thickness at the crown and thus reduce the fill in the approaches. Eleven feet clearance is ample for passenger vehicles. The grade-crossing eliminations in Chicago which I showed on the screen have only 8 feet at the curb and only 10 feet at the crown. They have to have service trucks go through, and the soffit of the arch of that Chicago bridge is all scratched up in consequence. We have had no difficulty as to inadequate clearance so far with bridges in operation over five years. That doesn't mean we never will have.

PROFESSOR JOHNSON: I would like to ask Mr. Hayden whether he ever made any use of Gottschalk's continustat. Gottschalk was an engineer from Buenos Ayres, — erstwhile Germany, — who came up here at one time and demonstrated his continustat. I think every one is familiar with it.

MR. HAYDEN: We did investigate the continustat, but found it was very much more restricted in application than the deformograph of Professor Beggs of Princeton University, and so we used that in preference. At present we use mathematical methods of analysis exclusively.

PROFESSOR JOHNSON: Of course, you would have to have a good many of the continustats, but I should think they might prove valuable.

MR. HAYDEN: You can approximate variation in moment of inertia in that way, but not very satisfactorily. Moreover, by the continustat you have to introduce such large deflections that considerable error is sometimes introduced. We compared results by the continustat, the deformograph and by mathematical methods, and found that the mathematical gave almost the same results as the deformograph, whereas the continustat in some peculiar cases introduced considerable error. So we concluded it was not always a practical method of analysis.

QUESTION: Has aerial photography been used in making surveys of the parkways?

MR. HOLLERAN: Yes. We had aerial photographs of the whole county made. There is a method now, by means of a stereopticon arrangement, whereby one can study the aerial photographs by using two photographs taken at a very slightly different angle, just as with the old-fashioned stereopticon. As perhaps you know, the two photographs which you used with the family stereopticon were not duplicates, but were taken at a slightly different angle. In the same manner, by taking two successive aerial photographs which overlap, you can put them under the stereopticon and see the terrain, in relief. We made

use of them to quite a great extent in making the original layout for some of our parkways. This is especially desirable where it is necessary to keep one's movements more or less secret. The method is used by the Public Utility Companies in laying out pipe lines, power lines and similar projects. Surveyors are never seen on the ground, and people don't know just where the routes are going until they are decided upon. We were able to lay the routes out on the maps without going out on the ground.

We got a very reasonable rate from the aërial photographers by giving them a chance to sell the photographs to others. The railroad companies and public utility companies have bought the prints quite largely, and that has enabled the airplane people to get their return on the original investment.

OF GENERAL INTEREST

AMERICAN SOCIETY OF CIVIL ENGINEERS

Fall Meeting, October 9, 10 and 11, 1929

The Boston Society of Civil Engineers takes great pleasure in welcoming to Boston the members of the American Society of Civil Engineers who attend the Fall meeting of that society on October 9, 10 and 11, and offers to the visiting guests such of its facilities, rooms, library and information as may be helpful at its headquarters in the rooms of the Engineering Societies of Boston, 715 Tremont Temple Building.

The features of interest in relation to this meeting are given below.

For the first time in fifty-one years the American Society of Civil Engineers will convene in Boston. Three conventions of the Society have been held in New England since the Boston meeting of 1878.

The Headquarters are to be at the Hotel Statler.

The sessions of the meeting will include many subjects of interest. It is desired that every New England member of the American Society, and particularly every member of the North-eastern Section, shall attend in order to welcome members from other sections of the country.

Members of the Engineering Societies of Boston are cordially invited to attend the technical session, which will be held

all day Wednesday, October 9, and Thursday, October 10. Student chapter members are especially invited.

Complete programs will be issued later. The major topic is the Metropolitan District—and there will be papers dealing with various phases of the development and engineering features of the district, including the parks, water supply, sewerage system, etc. Titles of papers and names of speakers will be published later.

On Thursday there will be meetings of the City Planning Division, the Highway Division, the Structural Division and the Division of Surveying and Mapping, and possibly Power Division, with several papers at each of these meetings.

A local committee has been planning for the entertainment of the members from outside New England and for the ladies who will attend as guests. On Friday an excursion is planned along the North Shore to Gloucester, with dinner at Swampscott at the New Ocean House. Arrangements are being made to accommodate those interested in special trips to points of engineering interest and to points of historical interest; auto routes to and from the convention, the air passenger service, golf club privileges, etc

Frontinus, the Water Commissioner

By Edward Grossman

(Note. — I want to express my grateful acknowledgments to Clemens Herschel's "Frontinus and the Water-Supply of Rome," from which most of the information for this article was gathered. It is a most interesting book.)

I

It is a regrettable fact that in ancient days they did not pay much attention to vital statistics; neither did the people themselves apparently keep track of their own birthdays. As long as they were alive, they knew that they were not dead, and that is about all they cared. This seems the only possible explanation for the vagueness of the date of Frontinus's birth.

Sextus Julius Frontinus was born of a patrician family some time in the period between the years 30 and 40. His birthplace is unknown, but is assumed to be Sicily, because a treatise on "Metes and Bounds" by one Julius Frontinus Siculus is classed with the writings of Frontinus. Little is known of his early life, except that he may have gone to Alexandria to study in the museum.

At the year 70 we find him a city prætor of Rome, a highly honorable office endowed with both judicial and executive functions, and generally held by men of patrician rank only. He owed this appointment to the Emperor Vespasian, whose policy it was to give positions in the Roman government to able and distinguished men from the country.

About the year 74 Frontinus was made Consul Suffectus. For a time he was

also Governor of Britain, where he held the Silures and other native tribes in check until succeeded by Agricola. On his return to Rome it is likely that he busied himself with his writings while waiting for his next appointment. It is thought that his "Treatise on the Art of War" was written at this time, fresh from his experiences in the war with the ferocious Welsh tribes.

Some time during the reign of Vespasian (69-79) Frontinus, probably at the request of the Emperor, wrote a work on the Roman colonies, giving details of boundaries, roads and other information which would be of interest in connection with the subject of taxation revisions, which was then under consideration.

A general treatise on surveying, by the indefatigable engineer, was written probably in the year 72, although the exact date is uncertain.

Between the time of his return from Britain and the year 97 there is little direct information on his life, except that in 83 he went to the Cattian War with the Emperor Domitian. The Catti were inhabitants of what are now the German states of Nassau, Hesse and part of Westphalia. He returned from this war in 84. It is thought that soon after began his "Strategemata," although one authority states that Frontinus wrote the work between the years 88 and 95. It likely took all that time to write the book, as will be seen from the description of it given by the author himself.

The "Strategemata" is a collection of anecdotes concerning distinguished warriors up to his time, and also their sayings, all classified and arranged according to the occasions when their precepts were to be put to use. The author of them says in his preface:

And, that they may be found in an order best calculated to distinguish such a variety of matters, I have divided them into three books, each of which forms a genus:

In the first are examples that relate to the affairs of an army previous to battle.

In the second, those which regard the battles and their consequences.

The third contains stratagems used in the attack and defence of places.

To each genus I have attributed certain species.

There are a dozen or more species in each book, some of the species being illustrated by fifty examples. Frontinus continues:

And, as it is less the desire of glory than that of being useful that has dictated both this and my other works, I shall consider myself rather assisted than undervalued by any additions that may be made to it.

Some unknown writer took him at his word and added another book called "Strategica" to the three of Frontinus.

During this period Frontinus was advanced to the position of augur. On September 19, 96, Domitian was assassinated and was succeeded by Nerva, who was inaugurated on December 18. With the coming of Nerva a "reform government" came into power. Not long afterward, in 97, Frontinus was appointed *curator aquarum*, or water commissioner of Rome. This was a great compliment to Frontinus, who was known as an honest and able man, disgusted with Domitian's reign. Nerva died in 98 and was succeeded by Trajan.

In 99 the Dacians, inhabiting portions of what is now Hungary, invaded Roman territory. Trajan went forth

against them. So highly did the Emperor think of the military genius of his water commissioner that it is likely he took him along. In 100 Trajan made Frontinus consul with himself. In 101 there was another war with the Dacians, but whether or not Frontinus went is unknown.

Before going to the wars he started a book of essays on farming, which he later finished.

II

Around the year 98 Frontinus began writing his masterpiece, "De Aquis Urbis Romae, Libri II." In this work he traces the history of the Roman water supply since the founding of the city, and describes minutely the working of the system.

From the foundation of the city, for 441 years (until 313 B.C.) the Romans were content with the waters they drew, either from the Tiber, or from wells, or from springs. Springs have held, down to the present day, the name of holy things, and are subjects of veneration, having the repute of healing the sick. . . . But now there run into the city: the Appian Aqueduct, Anio Vetus, Marcia, Tepula, Julia, Virgo, Alsietina, which is also called Augusta, Claudia, and Anio Novus. (De Aquis, Book I, chapter 4.)

The accompanying table gives a list of the Roman aqueducts under Frontinus's care, and some statistics about them. As is well known, these aqueducts were partly pipe lines, partly siphons, partly over arches, with here and there a little tunneling. Frontinus did not build any of them. His work was mainly confined to maintenance and the sale of water.

AQUEDUCTS UNDER FRONTINUS'S CHARGE

NAME OF AQUEDUCT	Date Built	Length in Miles	Height of Water Above Tiber Wharves (Feet)	Number of Delivery Tanks	AMOUNT IN QUINARIÆ		
					Taken from Taps, Actual	Used in City	Used Outside of City
	B.C.						
Appia	312	11	28	20	704	699	5
Anio Vetus	272-264	43	84	35	1,610	1,102	508
Marcia	145	61	125	51	1,935	1,098	837
Tepula	126	13	128	14	445	331	114
Julia	34	15	133	17	803	597	206
Virgo	21	14	35	18	2,504	2,304	200
	A.D.						
Alsietina-Augusta	10	{ 22 6 }	—	—	392	—	392
Claudia	50	46	158	92	5,625	3,824	1,801
Anio Novus	52	58	158				
	—	289	—	245	14,018	9,955	4,063

NOTE. — The Aqua Anio Novus is on top of the Aqua Claudia, these two comprising a double-decked aqueduct.

When he came into office a great deal of stealing was going on, both clandestinely and through just plain fraud. The clandestine stealing could, of course, be eliminated by means of a proper guard. To appreciate the other kind of stealing it is necessary to know something of the system of measuring used.

The Romans seemed totally unable to grasp the idea that in measuring the volume of flowing water the velocity of the current as well as its cross section must be considered, although Hero (first century B.C.) set forth that principle plainly, and many educated Romans had studied under him. Water was measured by the area of the cross section of the stream, or by the area of the orifice through which it flowed, whether the velocity was small or large.

The usual method of measuring water was to attach to the pipe or cistern a short length of pipe (ajutage) having the cross section paid for. These ajutages were stamped by the water department officials and attached under their supervision. The pipe leading from the ajutage was by law required to be fifty feet long and of the same inside diameter as the ajutage. These pipes were also stamped by the proper officials. However, "in some of the tanks, though their ajutages were stamped in conformity to their lawful admeasurements, it was found that pipes of greater diameter were attached to them. As a consequence, the water, not being held together for the lawful distance, and being, on the contrary, forced through the short, restricted distance, easily

filled the adjoining larger pipe" (Frontinus, chapter 112).

When Frontinus became water commissioner he ferreted out these different methods of stealing water, such as the one described in the above quotation of chapter 112, the tapping of underground pipes, the selling of water rights promiscuously so that the buyer may apply for a new *ajutage*, for which he paid, using the water free from the old, and similar tricks. He must have had a busy time of it at first.

The *quinaria* was, in general, a circular orifice (inside cross-sectional area of a unit *ajutage*) having an area equal to 0.632 square inch. Velocity, it must be remembered, was not taken into consideration by the Romans. Therefore, since the waters in the various aqueducts moved with different velocities, the *quinariæ* differed. Thus, where the velocity was 1 foot-second, a *quinaria* equaled 0.0044 cubic foot-second, or 2,850 gallons in 24 hours; and where the velocity was 3.25 foot-second, a *quinaria* equaled 0.0143 cubic foot-second, or 9,250 gallons in 24 hours. A most delightful way to keep down the cost of living.

Now, Frontinus knew this was wrong — that the system of measurement should be revised, but unfortunately he was unable to give a reason for his "hunch," for he did not know enough hydraulics. Nevertheless, whatever he may have lacked in his knowledge of hydraulics he more than made up in his capacity as an administrator. He put the waterworks on a business basis, as far as it was possible to do so. Into this work he put a tremendous zeal and love, as will be shown by his own words.

Inasmuch as every office conferred by

the Emperor demands special attention, and inasmuch as I am moved not only to devote diligence, but even love, to any matter confided to my care . . . and inasmuch as Nerva Augustus . . . has now imposed upon me the duties of water commissioner, . . . I therefore consider it to be the first and most important thing to be done, as has always been one of my principles in other affairs, to learn thoroughly what it is that I have undertaken.

There is, indeed, no better foundation for any business; nor can it in any other way be determined what is to be done and what omitted.

It has seemed to me not superfluous to examine consecutively the lengths of channel of each aqueduct in its several parts, and in detail; this because the maintenance of the works is the most important part of the duties of this office, wherefore it is necessary that whoever is placed in charge of them should know which ones are in need of having money spent on them.

There were, be it noted, in the aggregate, 12,755 *quinariæ* recorded and 14,018 discharging water; that is, 1,263 more were reported as delivering water than had been received. Astonished at this, I felt it to be no small part of my duty to investigate so as to arrive at reliable data concerning the aqueducts and their discharge, and to see how it would come about that more was being delivered than belonged, so to speak, to the estate; so before doing anything else I set about to measure the intake of the conduits.

After completing his measurements, he was able to locate where the stealing was going on and do whatever he could to stop it.

Thus he lived on for seven years, finishing his engineering and literary labors in 104, when he died, aged about sixty-nine years.*

* This age is, of course, approximate, since the exact year of his birth is not known. There may be a variation of five years either way.

PROCEEDINGS OF THE SOCIETY

APPLICATIONS FOR MEMBERSHIP

[September 20, 1929]

THE By-Laws provide that the Board of Government shall consider applications for membership with reference to the eligibility of each candidate for admission and shall determine the proper grade of membership to which he is entitled.

The Board must depend largely upon the members of the Society for the information which will enable it to arrive at a just conclusion. Every member is therefore urged to communicate promptly any facts in relation to the personal character or professional reputation and experience of the candidates which will assist the Board in its consideration. Communications relating to applicants are considered by the Board as strictly confidential.

The fact that applicants give the names of certain members as reference does not necessarily mean that such members endorse the candidate.

The Board of Government will not consider applications until the expiration of fifteen (15) days from the date given.

For Admission

BOLDE, ABRAHAM CHARLES, Dorchester, Mass. (Age 31, b. Russia.) Am a graduate of Harvard Engineering School, class of 1923, in sanitary and municipal engineering. From September, 1923, to January, 1926, was employed as sanitary engineer by the Massachusetts Department of Public Health, examining water supplies and sewage disposal systems, surveying, reporting and drafting; resigned this position in January, 1926, to

travel abroad, and was absent six months; upon my return was employed as resident engineer on a water main project by Symonds & Stevens, and upon the completion of this work was again employed by the Massachusetts Department of Public Health; In October, 1927, became engineer with the South Essex Sewerage District, making an investigation of manufacturing wastes in the district and also of the pollution of North River; also designed and was in charge of constructing the first waste carbonating plant in this State; at present employed as sanitary engineer by the South Essex Sewerage District. Refers to *H. W. Clark, G. M. Fair, F. H. Kingsbury, H. A. Symonds, A. D. Weston.*

DAYTZ, ALEXANDER B., Roxbury, Mass. (Age 26, b. Russia.) Graduate of Massachusetts Institute of Technology in June, 1928. From June, 1928, to July, 1929, structural detailer for Phoenix Bridge Company; July, 1929, to date, designing engineer for Boston & Maine Railroad. Refers to *J. B. Babcock, Eugene Mirabelli, C. M. Spofford, Hale Sutherland.*

KAMILAKIS, MINAS S., Boston, Mass. (Age 23, b. Greece.) Am a senior at Northeastern University. During co-operative periods have been employed by the National Map Committee, at Babson Park, Wellesley Hills, Mass.; by town of Milton as a rodman; by Fink & Fink, Boston, as a rodman. Refers to *W. J. Alcott, H. B. Alword, C. O. Baird, W. E. Nightingale.*

METCALF, PHILIP SHERIDAN, Boston, Mass. (Age 23, b. Portland, Maine.) He is a high school graduate and attended Colby College for two years. In October, 1925, he was engaged as a draftsman by Haven & Hopkins, and remained with

them until April, 1928. The next six months he was employed by the Associated Factory Mutual Fire Insurance Company as designing draftsman; in July, 1929, he entered the employ of Jackson & Moreland as structural draftsman. Refers to *E. H. Cameron, J. S. Crandall, R. H. Lindgren, F. N. Weaver.*

MOTA, CANDELARIO CALOR, Porto Rico. (Age 31, b. Aguadilla, Porto Rico.) Graduate of Massachusetts Institute of Technology, class of 1924, degree of B.S. in civil engineering. In 1924-25, assistant engineer in the Department of the Interior, Porto Rico; 1925-26, instructor in civil engineering, University of Porto Rico; 1926-29, assistant professor in same; during summer of 1929, with Robinson & Steinman in bridge department, American Bridge Company. Refers to *G. L. Hosmer, C. M. Spofford, Hale Sutherland, R. G. Tyler.*

WEST, WILLIAM BENJAMIN, Boston, Mass. (Age 34, b. Alabama.) Graduate of Alabama Polytechnic Institute, 1918. From 1918 to 1923, in service of United States government and writer on engineering subjects: September, 1923, to January 15, 1924, in designing department of Alabama Power Company on transmission line calculations; January 19, 1924, to June, 1926, embarked on private studies along line of engineering publicity; June 9, 1926, to February 9, 1929, employed by Brooklyn Edison Company in electrical engineer's department on inspection

of electrical equipment, plans for electrification of Ward Baking Company, etc.: February, 1929, to date, with New England Power Construction Company as electrical draftsman and checker. Refers to *H. K. Barrows, E. A. Dow, C. M. Durgin, C. T. Main.*

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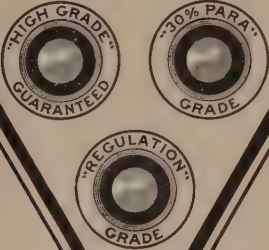
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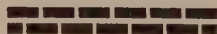
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